Constraining Dark Matter Models Through 21cm Observations

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2nd UniverseNet Meeting

SEEKING LINKS BETWEEN FUNDAMENTAL PHYSICS AND COSMOLOGY

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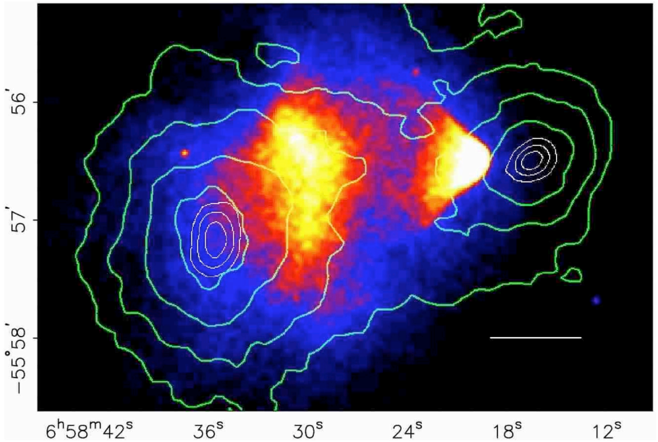
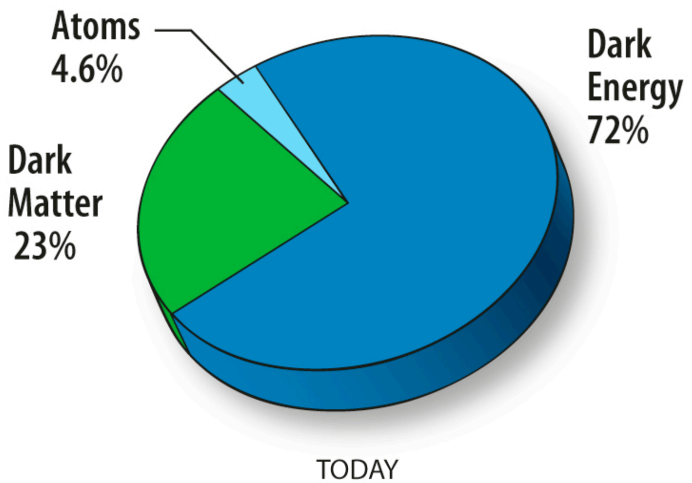
Evidence for DM

- On galactic scales:
  - Rotation curves of galaxies;
  - Weak gravitational lensing;
  - Velocity dispersion of dwarf spheroidal galaxies;
  - Velocity dispersion of spiral galaxy saltellites;



- On the scale of galaxy clusters:
  - Distribution of radial velocities;
  - Weak gravitational lensing;
  - X-ray emission;



- On cosmological scales:
  - CMB anisotropy spectrum;
  - Matter power spectrum.

DM Candidates

.... What is the Dark Matter made of ?

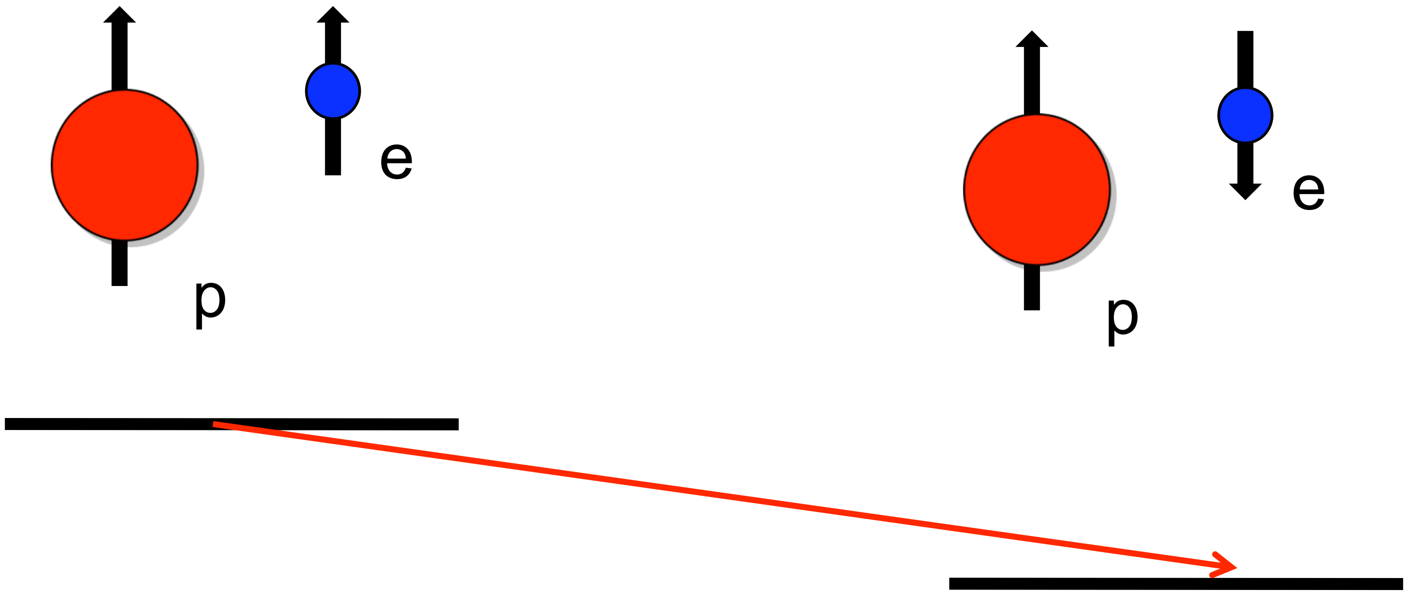
Supersymmetric particles, Kaluza Klein particles, sterile neutrinos, majorons, light dark matter, axions, x-citing DM, little Higgs, wimpzillas, Q-balls…

... How to detect Dark Matter? (and, even better, how to discriminate different candidates?)

- *Direct detection: look for the interaction of DM particles with the nucleons in the detector;*
- *Indirect detection: observe the products of DM annihilations/ decays (gamma, neutrinos, positrons, antiprotons..):*
- *Radio observations can probe the heating history of the IGM*

The 21cm line

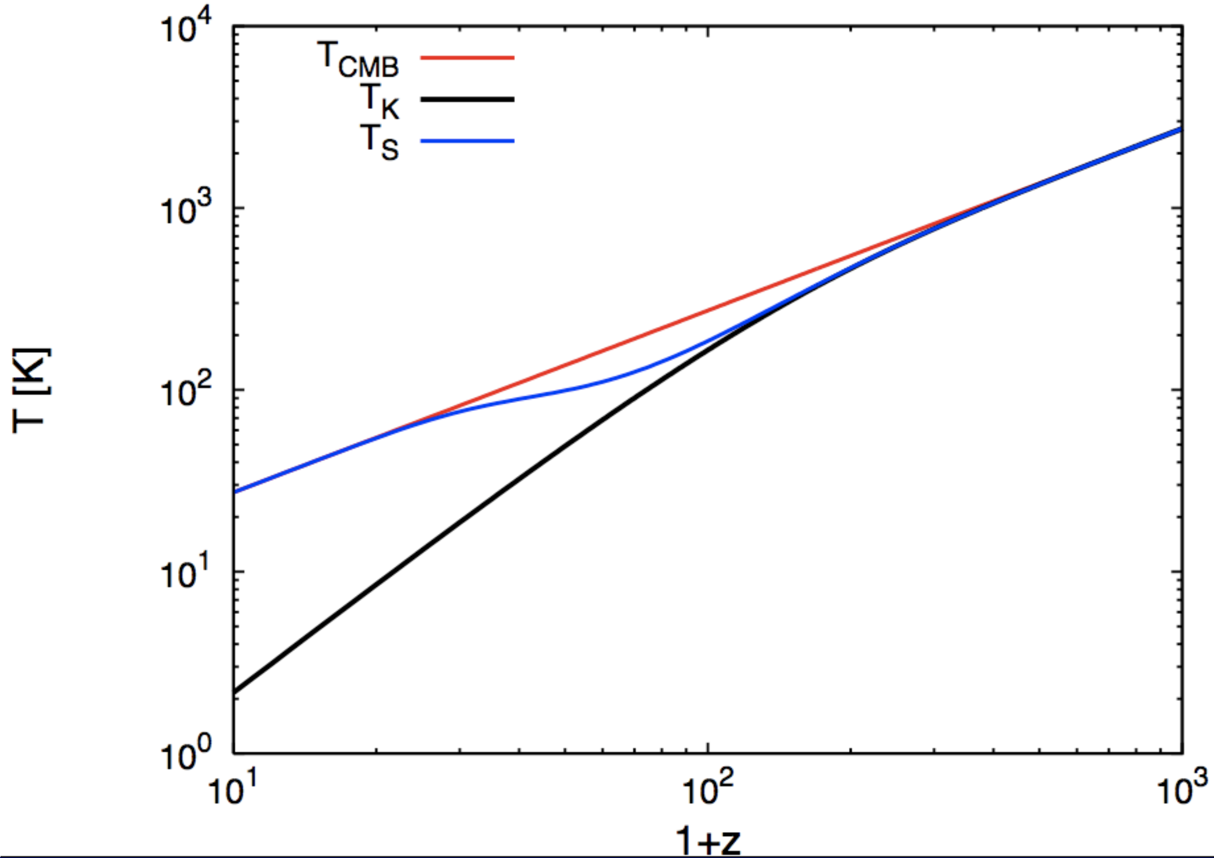
The abundance and density of neutral hydrogen can be probed by looking at the 21cm H line, associated to the hyperfine transition from the triplet to the singlet state



$$\Delta E = (21\text{cm})^{-1} = 1420 \text{ MHz} = 6 \times 10^{-6} \text{ eV} = 6.8 \times 10^{-2} \text{ K}$$

The 21cm signal

$$\delta T_b \simeq 26\ \mathrm{mK}\ x_{\rm HI} \left(1 - \frac{T_{\rm CMB}}{T_S}\right) \left(\frac{\Omega_b h^2}{0.02}\right) \times \left[\left(\frac{1+z}{10}\right)\left(\frac{0.3}{\Omega_{\rm M}}\right)\right]^{1/2},$$



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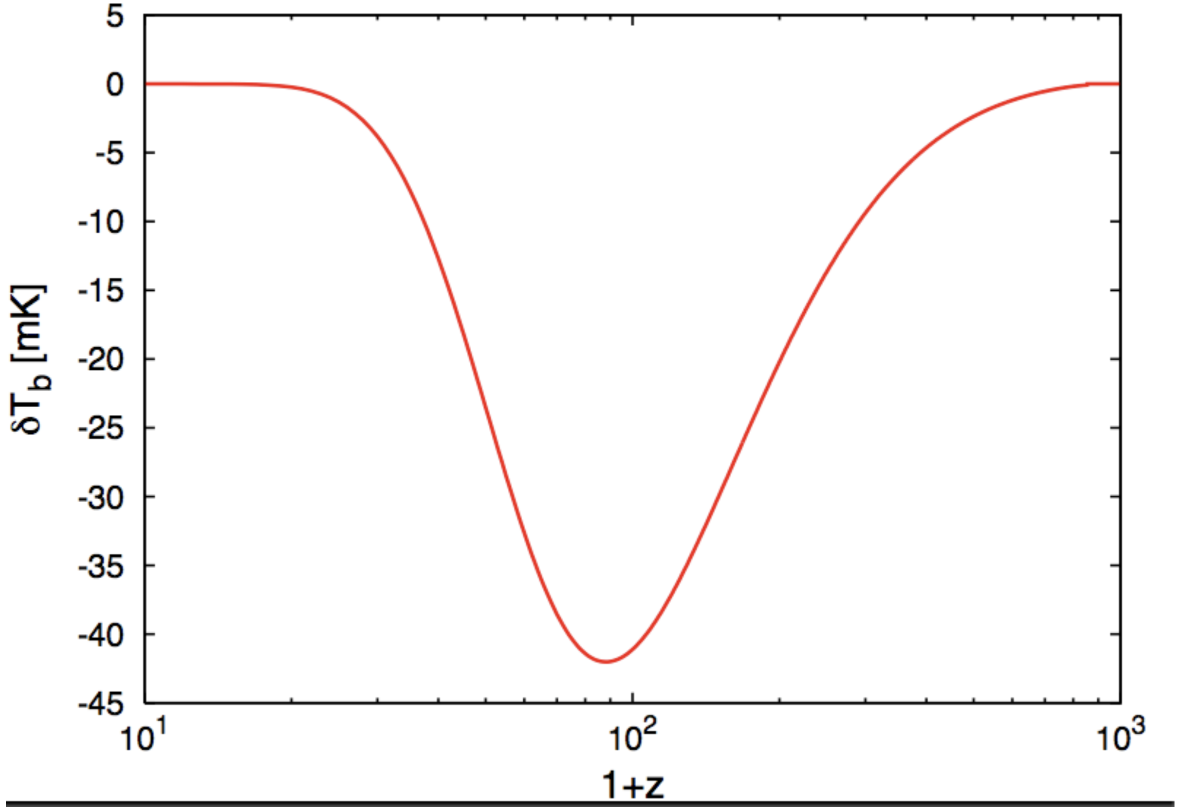


DM energy injection

Dark matter can inject energy into the IGM through its annihilation products.

$$\dot{\epsilon} = \frac{1}{2} \underline{f_{\rm abs.}} \frac{n^2_{\rm DM,0}}{n_{\rm H,0}} \langle \sigma_{\rm ann.} v \rangle m_{\rm dm} (1+z)^3 \, \underline{C(1+z)}$$

This will change the thermal and ionization history of the Universe, leading to a different 21cm signal.

The changes will depend on the spectrum of annihilation/decay products, and thus *will be different for different kinds of DM particles.*

Annihilating DM candidates

We consider two kinds of annihilating DM: neutralino DM and light DM.

The neutralino is (usually) the lightest supersymmetric particle (LSP) in SUSY theories. It is a superposition of higgsinos and gauginos.

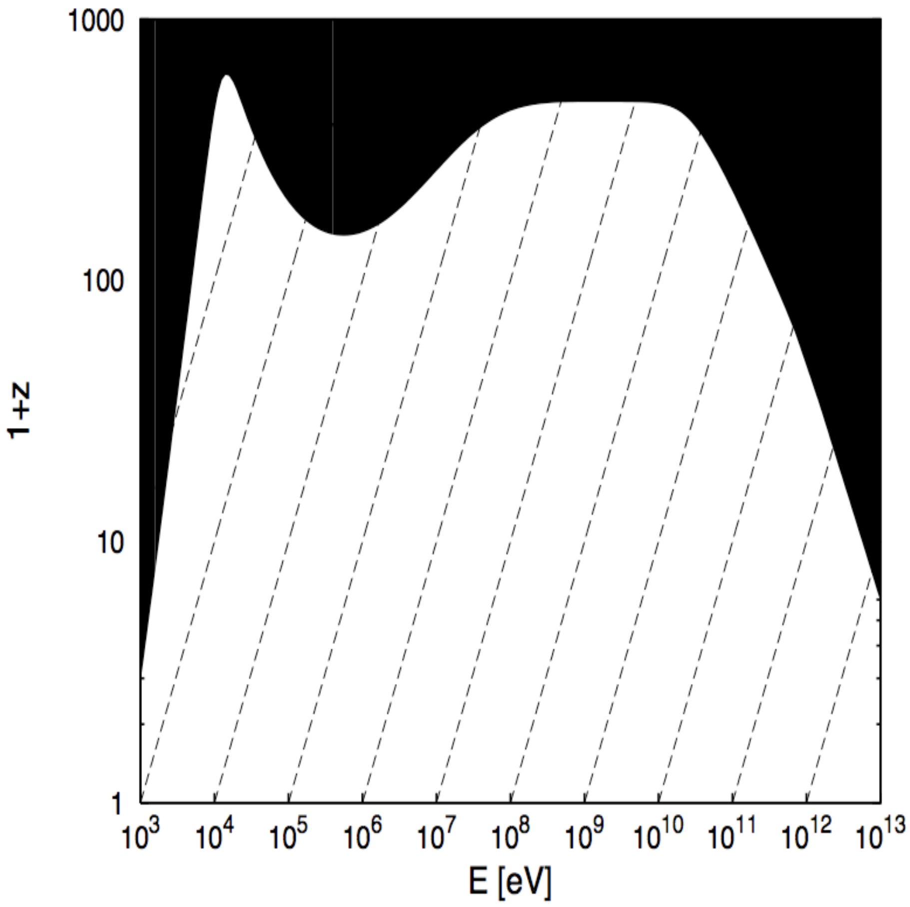
Neutralinos mainly annihilate to heavy quarks, W bosons, and tau leptons. The branching ratios depend on the gaugino fraction. We consider 4 different neutralino models with masses from 50 to 600 GeV.

Light dark matter is composed of scalar particles with mass in the MeV range. It was introduced to explain the INTEGRAL 511keV signal. We consider two cases m=3 and 20 MeV.

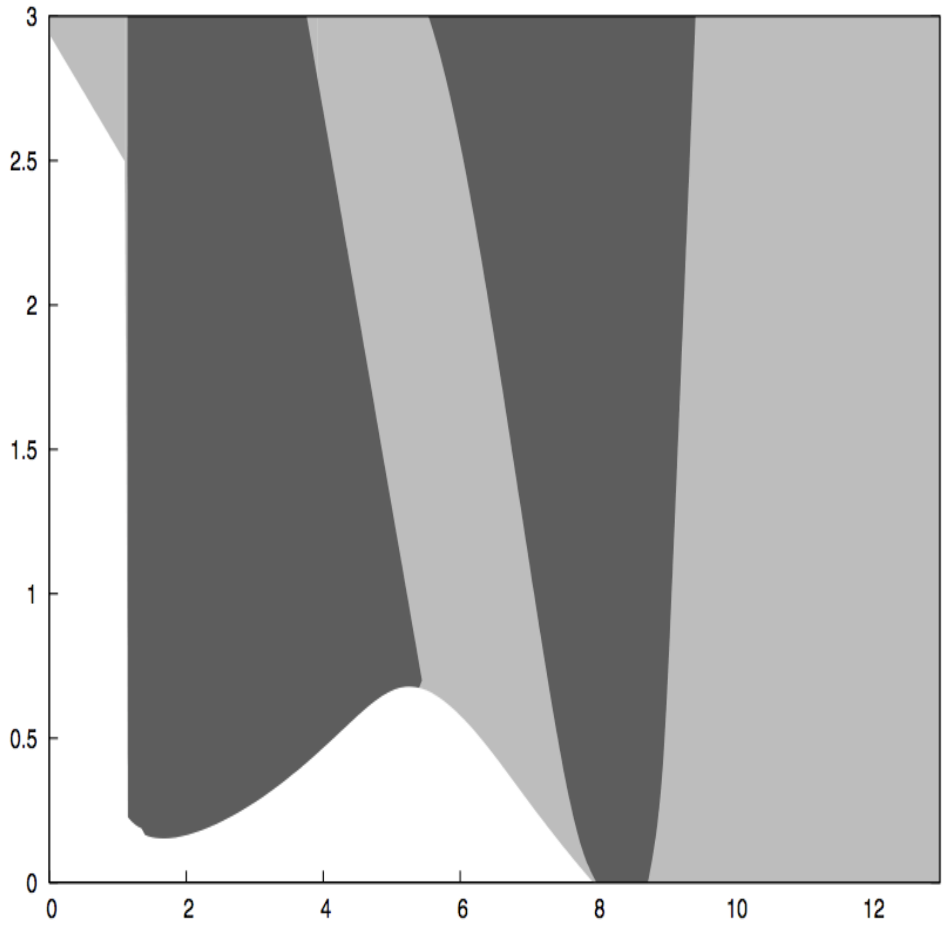
LDM annihilates directly to electron-positron pairs.

Transparency windows

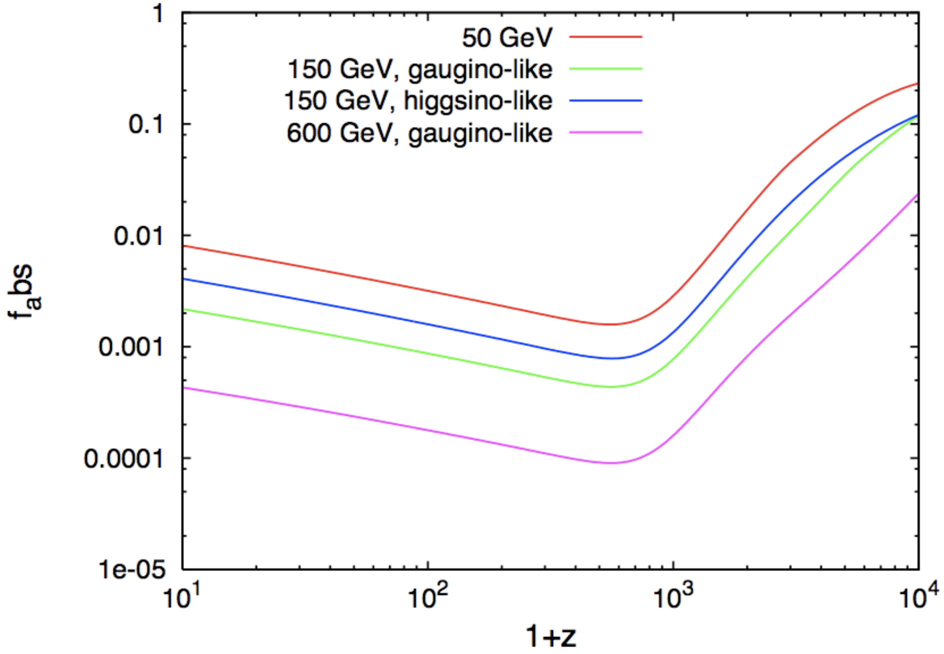
Photons:

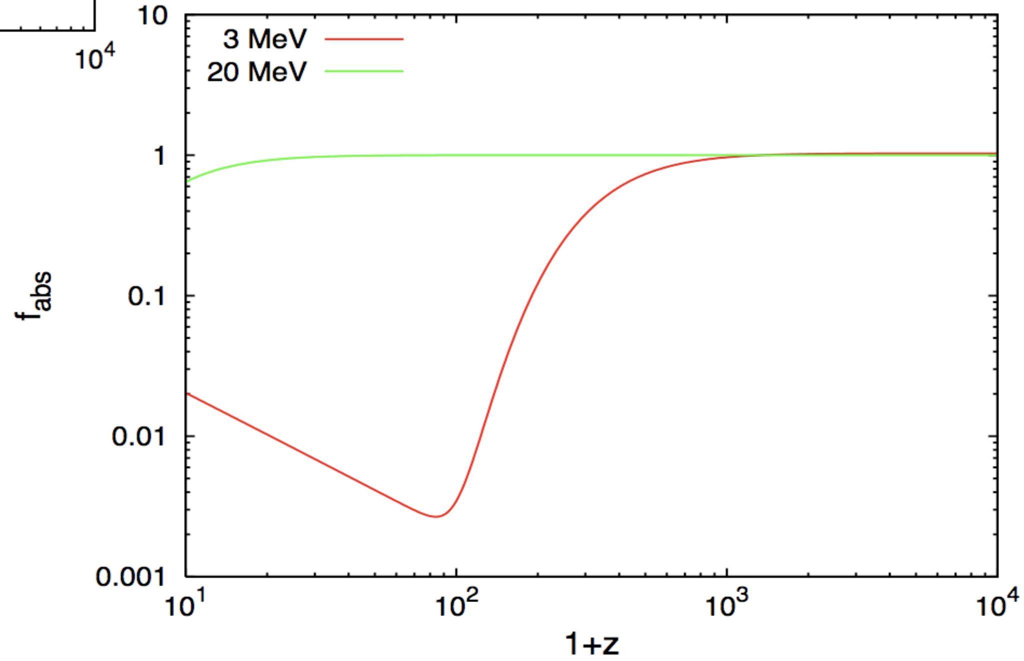


Electrons/positrons



Transparency windows





The Clumping Factor

The annihilation rate scales like (density)^2

This means that the annihilation rate is enhanced in high density region (contrarily to what happens to decay rate).

The enhancement is proportional to $\langle\rho^2\rangle / \langle\rho\rangle^2$

We incorporate this effect into the ***clumping factor*** C(z).

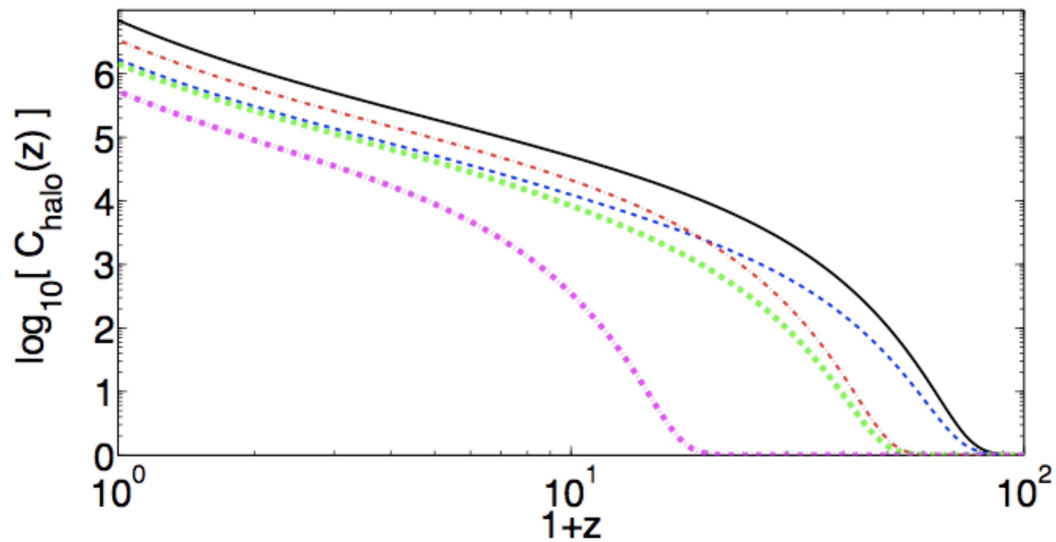
The CF depends on the halo mass function (i.e. on the mass distribution of halos) and on the halo density profile.

We used the recent results by Diemand et al. (2008)

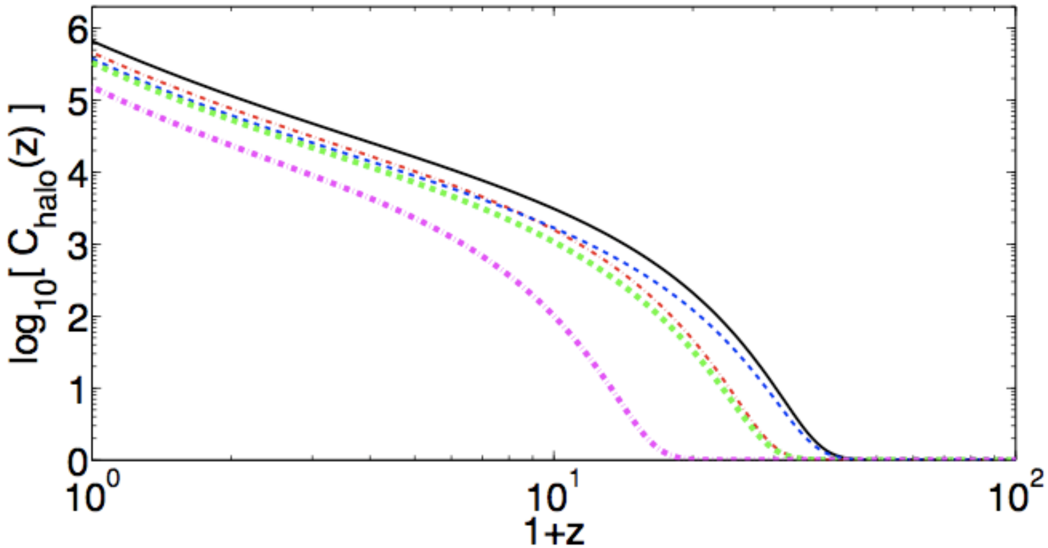
We take into account free streaming (for LDM)

We also take into account several generations of substructures inside halos.

The Clumping Factor

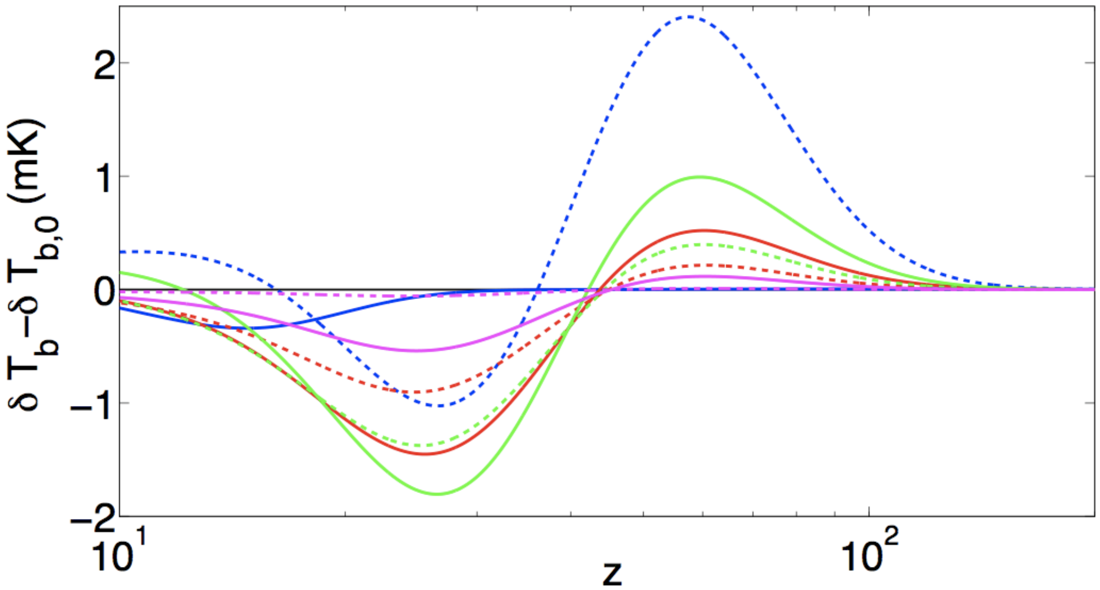


CDM (NFW profile)



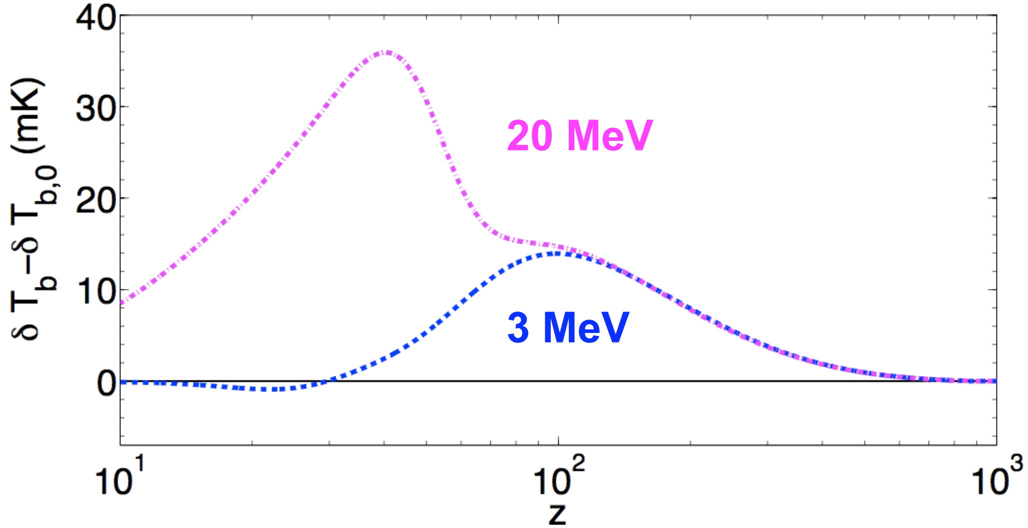
WDM (Burkert profile)

Brightness temperature



Neutralino DM

LDM



(Cumberbatch, ML, Silk, arXiv:0808.0881

Submitted to MNRAS)

Perspectives for exp. detection

The LOw Frequency ARray (LOFAR) uses an array of ~25000 omni directional antennas, arranged in clusters spread out over an area of 350km of diameter.

One of the key projects of LOFAR is the observation of the 21cm signal ("Epoch of reionization" project).

LOFAR will observe the 115-180 MHz range, corresponding to $6 < z < 12$

The cosmological signal is contaminated by many astrophysical and non-astrophysical components.

Preliminary results show however that it will be possible to reach a sensitivity of few mK at z~10.

This would be enough to detect a "heavy" LDM candidate.

Conclusions

- We have strong evidence for the existence of DM, from different observations at different scales;
- Many theoretically motivated candidates exist;
- Many experiments aim to detect DM directly, or its annihilation products;
- The 21cm signal probes the heating/ionisation history of the Universe, and can be affected by the presence of DM, giving characteristic signatures;
- LDM gives a signal that could be detected by LOFAR;
- Neutralino dark matter is beyond LOFAR reach... maybe in the future?